DYNAMIC RECONFIGURATION FOR MAXIMIZING THE OVERALL LINK EFFICIENCY OF ENERGY RECEIVERS IN A RELIABLE IMPLANTABLE SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional patent application 62/244,456, filed on Oct. 21, 2015, and hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] This invention relates to acoustically powered implanted devices.

BACKGROUND

[0003] Implanted medical devices are of increasing interest for a wide variety of medical applications. Providing power to implanted medical devices has been performed in various ways. For example, power can be provided to implanted medical devices using RF (radio frequency) radiation or inductive coupling. Another approach is ultrasonic power transmission, which is expected to provide better performance than electromagnetic power transmission for implanted devices in some cases. US 2014/0336474 provides examples of ultrasonic power transmission, and is hereby incorporated by reference in its entirety.

[0004] However, the design considerations for efficient power transfer in an ultrasonic power transmission system are substantially different from those that arise in connection with electromagnetic power transmission for implanted devices. Therefore, design approaches suitable for providing efficient electromagnetic power transmission to implanted devices aren't applicable to ultrasonically powered implanted devices. Accordingly, it would be an advance in the art to provide improved ultrasonic powering of implanted devices.

SUMMARY

[0005] The main idea of this work is to provide efficient power transmission from an acoustic transmitter to an electrical load on an implanted device using a control system that at least varies the transmitted acoustic frequency. This unusual feature of varying the transmitted frequency can have many effects on system performance, but the effect of greatest interest is its influence on the electrical impedance of the acoustic transducer in the receiver that receives power from the transmitter. This ability to vary the transducer impedance can be used to optimize power delivery to the load via impedance matching, where it is understood that the impedances being matched may depend on power or other operating conditions of the system (i.e., the overall system is typically nonlinear).

[0006] In most cases, the real part of the transducer impedance will roughly match the real part of the impedance looking into the matching network, while the imaginary part of the transducer impedance is positive (i.e., inductive) and can be compensated using an adaptive and purely capacitive matching network. This advantageously avoids the need to use inductors as separate components for impedance matching. Such avoidance of discrete inductors is beneficial because in the frequency range of interest, the physical size of typically required discrete inductors is too large for use in miniaturized applications like implanted medical devices.

[0007] To better appreciate this work, it is helpful to state the problem to be solved more explicitly, with reference to the example of FIG. **2**. The total efficiency of the link is a product of the efficiencies of all the sub-blocks of the system, as shown in FIG. **2**. η_{source} includes the efficiency and effective aperture of the Tx (transmitter). η_{medium} includes channel losses, including but not limited to: propagation losses, diffraction, attenuation, reflections, impedance mismatch of mediums, changes in range, misalignment and rotation. η_{rec} is the efficiency and effective aperture of the Rx (receiver). η_{match} refers to the impedance match efficiency between the power receiver and the matching network as well as any losses in the matching network itself. $\eta_{circuit}$ includes the efficiency of the power recovery circuit. It can be noted that maximum overall link efficiency will be obtained by tweaking each of these individual efficiencies, and is not necessarily achieved at the maximum of any or all of these individual efficiencies. During the operation of a wireless power system, several factors may change or affect the individual components of the system which can produce a degradation in efficiency:

1) The Tx properties including efficiency, impedance and beam pattern could change over time, potentially due to any environmental variations, physiological state, positional drift or rotation, or any objects surrounding the Tx.

2) The medium between the Tx and the Rx can be perturbed, for instance: the distance between the Tx and Rx can change, objects may enter the medium, the properties of the medium could change due to temperature, pressure variations or physiological state, etc.

3) Like the Tx, the Rx properties including efficiency, impedance and aperture could also change over time, potentially due to any environmental variations, physiological state, positional drift or rotation, or any objects surrounding the Rx.

4) The properties of the matching network and the power recovery circuits could change due to environmental factors such as humidity and temperature variations.

5) The electrical load is a function of the desired tasks being performed, which can fundamentally change due to different applications, as well as over time from different operation modes in a system.

[0008] If the system is originally operating in a desired state, these aberrations will lead to drift from that original intended operating point over time. This will lead to a sub-optimal operation of the system. The purpose of the control system as described herein is to address this problem.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a block diagram of an embodiment of the invention.

[0010] FIG. **2** is a more specific exemplary block diagram of an embodiment of the invention.

[0011] FIG. **3**A shows the frequency dependence of the impedance of an exemplary acoustic transducer.

[0012] FIG. **3**B shows the power conversion efficiency of the exemplary acoustic transducer of FIG. **3**A.

[0013] FIG. **4** shows two examples of matching networks.

[0014] FIG. **5** is a diagram showing an embodiment of the invention having a wearable acoustic transmitter in communication with a mobile device.